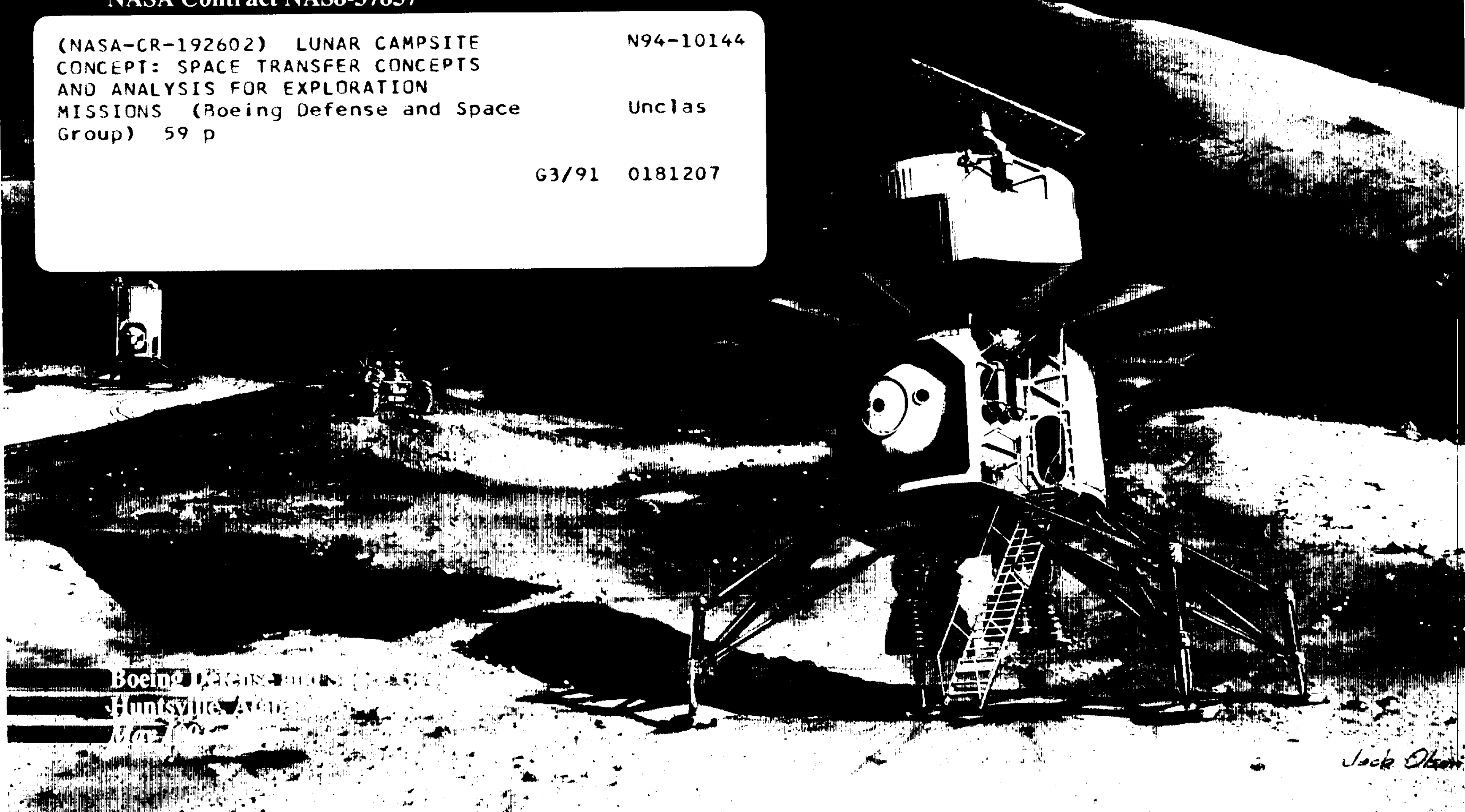
BOEING

# Lunar Campsite Concept

## Space Transfer Concepts and Analysis For Exploration Missions

NASA Contract NAS8-37857





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# Lunar Campsite Team



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# Acronyms

| | |
|---|---|
| ACRV | Assured Crew Return Vehicle |
| ACS | Attitude Control System or Atmoshere Control System |
| ARS | Atmospheric Revitalization System |
| BMR | Body Mounted Radiator |
| C&T | Communications & Tracking |
| CHeC | Crew Health Care System |
| CRV | Crew Return Vehicle |
| CV | Crew Vehicle |
| DMS | Data Management System |
| ECLS(S) | Environmental Control & Life Support System |
| EMCC | Eight Man Crew Configuration / Capability |
| EPS | Electrical Power System |
| EVA | Extra-Vehicular Activity |
| FDS | Fire Detection and Suppression |
| GN&C | Guidance Navigation & Control |
| IAV | Internal Audio / Video |
| LCV | Lunar Crew Vehicle |
| LEO | Low Earth Orbit |
| LLO | Low Lunar Orbit |
| LTF | Lunar Transportation Family |
| LTV | Lunar Transportation Vehicle |
| MLI | Multi-Layer Insulation |
| MSFC | Marshall Space Flight Center |
| MWS | Maintenance Work Station |
| PHF | Personal Hygiene Facility |
| RCS | Reaction Control System |
| SPDA/TPDA | Secondary / Tertiary Power Distribution Assembly |
| STCAEM | Space Transfer Concepts & Analysis for Exploration Missions |
| TCS | Thermal Control System |
| TD | Technical Directive |
| THC | Temperature & Humidity Control |
| TLI | Trans-Lunar Injection |
| WRM | Water Recovery & Management |

# Lunar Campsite Summary

The lunar Campsite concept responds to a perceived need to identify early manned science and exploration missions that require minimal initial funding. The Campsite concept defers the build-up of many infrastructure components without escalating total program costs. The lunar Campsite has been sized nominally for four crew for 42 days (1 lunar night and 2 lunar days), but can be modified to span two lunar nights up to 60 days. Total mission fulfillment requires five Earth-to-LEO launches, four (100 mt class launch vehicle) for the two vehicle assemblies and one (PLS or NSTS) for the crew. The lunar Campsite mission mode is tandem direct using a booster stage and a lander stage. The booster is separated from the lander after the TLI burn and is expended into the Earth's atmosphere. In the Campsite mode, the lander lands on the surface not to be returned. In the crew delivery mode, the lander is guided to a precision landing about 500 m from the Campsite, and with enough propellant to return the crew to Earth. The Campsite consists of a habitat and airlock, body-mounted radiators with a surface shield, sun tracking solar arrays, and an Earth-tracking high-gain antenna. The CV is very similar to the campsite delivery vehicle. The CV does not, however, have radiators or solar arrays. The vehicle stacks are essentially common in that they utilize the same structure system and engines, the same propellant tanks, the same "cut-out" in which the CRV and payloads are incorporated, and the same RCS locations. The booster and lander stage propellant tank propellant capacities are identical and have margins which would allow additional fueling for propulsive capture of the boost stage into Earth orbit.

The initial Campsite concept was developed by Boeing in an IR&D funded effort. This contractual study was performed to identify Campsite and vehicle interfaces and vehicle requirements, and to surface issues related to the integration of the Campsite and LTVs.

ADVANCED CIVIL SPACE SYSTEMS

# Lunar Campsite Summary

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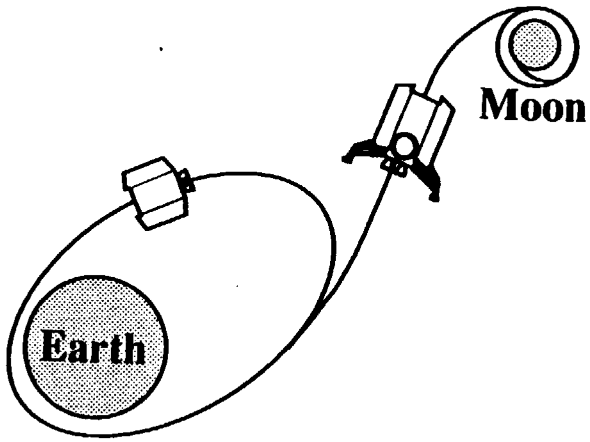
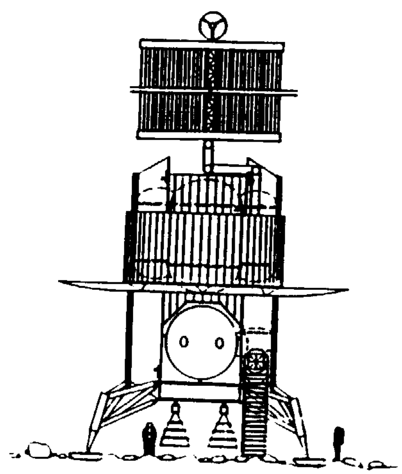



- System provides early science and exploration capabilities at reduced initial costs
- Unmanned, fully-integrated system launched to LEO (initial mass = 99.3 mt)
- Rendezvous with previously launched boost stage (initial mass = 82.3 mt)
- Tandem direct flight to the lunar surface
- Crew delivered in second tandem direct flight
- Boost stages return to Earth and can be expended or propulsively captured for reuse



- Campsite self-deploys / activates and are checked-out prior to crew arrival
- Includes closed ECLS and regenerable power systems, which allow multiple non-contiguous 30 to 60 day missions for 4 crew
- CV lands $\geq$ 500 m from Campsite and crew transfers with supplies on rover
- CV provides added level of redundancy to the Campsite

# Concept Rationale

The lunar Campsite concept responds to the need for early missions with greatly reduced costs over concepts requiring extensive infrastructure while providing for early science and exploration. This concept defers the build-up of a large infrastructure without escalating total program costs. The campsite serves early exploration needs while providing "construction shack" capabilities when infrastructure build-up begins. Other functions that it can perform include remote exploration in conjunction with the base infrastructure, man-tended science, emergency shelter, or as the beginning piece of the lunar base infrastructure.

# Concept Rationale



- Uses current state-of-the-art technology and is near-term achievable
- Capability for early manned missions with minimal costs
- Reduces initial costs by deferring infrastructure, minimizing flight elements and avoiding on-orbit assembly
- Uses the same basic propulsion stage for all vehicles
- Provides early overnight surface operations capability
- Provides "construction shack" for permanent base emplacement
- Uses: remote exploration base, man-tended or assembled science station, emergency shelter, permanent base seed, or construction shack

# Requirements / Assumptions

The lunar Campsite has been sized nominally for four crew for 42 days (1 lunar night and 2 lunar days), but can be modified to span two lunar nights up to 60 days. The Campsite is designed to accommodate multiple, non-contiguous missions to survive on the lunar surface, and to communicate with ground operators during unoccupied periods. Total mission fulfillment requires five Earth-to-LEO launches, four for the two vehicle assemblies and one for the crew. The first two heavy-lift launches provide a complete campsite delivery vehicle which is sent to the lunar surface and checked out prior to crew delivery. The CV requires the same two heavy-lift launches as the Campsite with a subsequent crew delivery flight in the Shuttle or a man-rated expendable launch vehicle.

# Requirements / Assumptions



- Sized for four crew for 30 to 60 day tours
- Requires two lunar surface flights
  - Campsite delivery (cargo flight)
  - Crew delivery (manned CV flight)
- Uses 100 mt unmanned ETO launch vehicle with 10 m dia. shroud
- LEO rendezvous and docking of stages
- Crew delivery via Shuttle or man-rated expendable launch vehicle
- Designed for multiple non-contiguous missions
- Campsite systems self deployed and activated prior to crew arrival for system validation
- Campsite status monitored from Earth
- CV lands $\geq$ 500 m from Campsite
- Tele-rovers brought by Campsite and first CV
- CV provides redundancy for Campsite

# Critical Campsite Questions

Listed are the six critical open areas identified as the starting point for current configuration design and vehicle integration efforts. As before in the STCAEM study, precisely those issues whose resolution had so far appeared least defined or most difficult were targeted to be the chief decision drivers for the current design iteration.

# Critical Campsite Questions

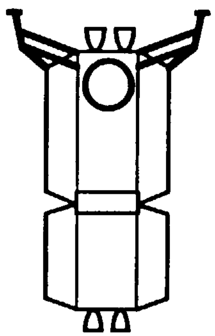


- Type of CRV
- CRV integration
  - Location (crew egress, propulsion interaction, launch escape)
  - Orientation (crew posture and visibility for landing)
- Upgrade scars
- Module integration with vehicle bus
  - Landing blast protection
  - Subsystem integration with vehicle
- Relationship between the two landers
  - Realistic proximity
  - Provisions for lugging supplies/samples back and forth
- Robotic provisions

# Operating Mode

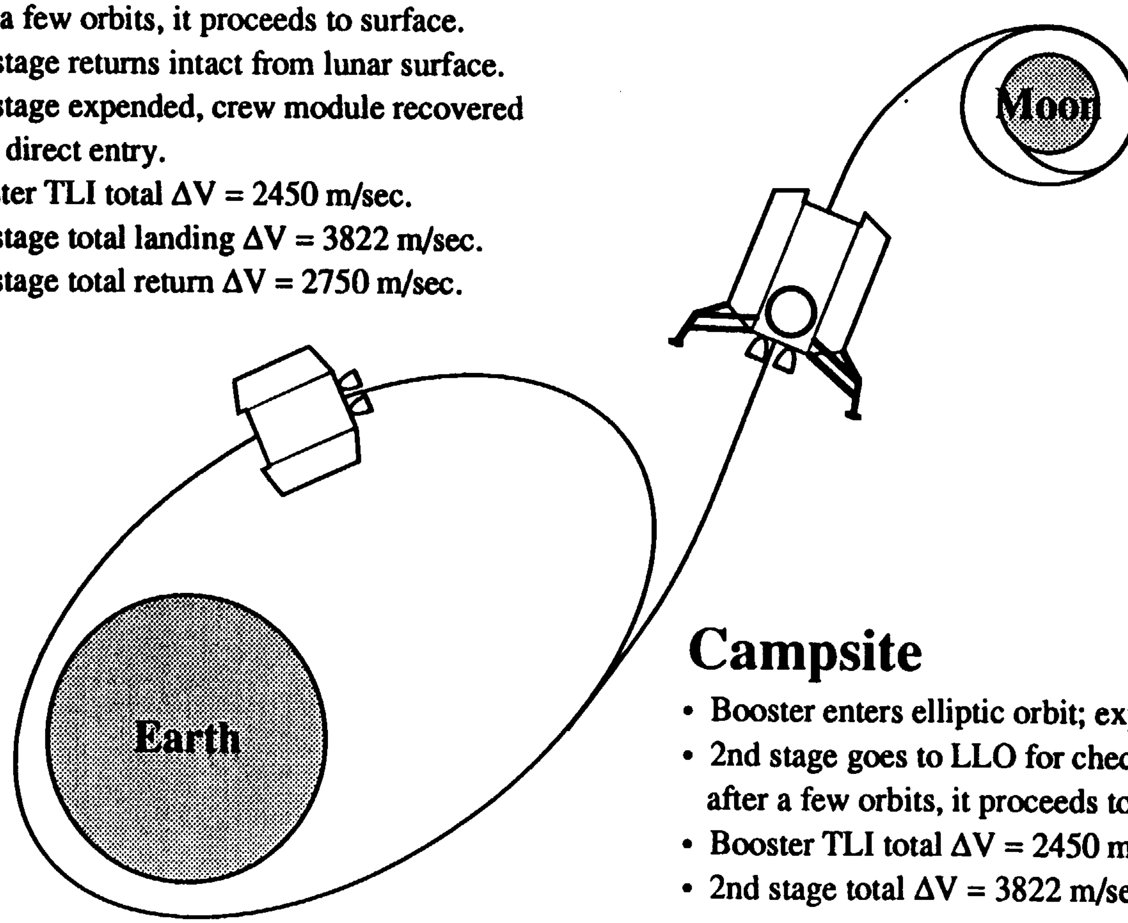
The lunar Campsite mission mode is tandem direct using a booster stage and a lander stage. Each stage is designed to be launched in a launch vehicle with a 10 m diameter, 100 mt payload capacity, and docked together in LEO prior to TLI. The booster is separated from the lander after the TLI burn and is expended into the Earth's atmosphere (the boost stage could be recovered in LEO for eventual re-use with the incorporation of an aerobrake or about 20 mt of additional propellant). In the Campsite mode, the lander lands on the surface not to be returned. No lunar orbit rendezvous (LOR) both reduces complexity (lunar orbit operations are confined to a few revolutions prior to landing and prior to trans-Earth injection for alignment, checkout and $\Delta V$ savings) and allows a greater choice of lunar surface landing sites due to elimination of orbital constraints inherent to rendezvous. In the crew delivery mode, the lander is guided to a precision touchdown about 500 m from the Campsite with enough propellant to return the crew to Earth. The penalty of returning the entire CV to Earth is compensated by maintaining vehicle commonality with the Campsite and by not attempting to de-integrate the CV on the lunar surface. The crew perform a direct-entry at Earth in the same capsule that sustains them for the entire trip.

# Operating Mode



## Crew Vehicle

- Booster enters elliptic orbit; expended.
- 2nd stage goes to LLO for checkout & alignment; after a few orbits, it proceeds to surface.
- 2nd stage returns intact from lunar surface.
- 2nd stage expended, crew module recovered with direct entry.
- Booster TLI total $\Delta V = 2450$ m/sec.
- 2nd stage total landing $\Delta V = 3822$ m/sec.
- 2nd stage total return $\Delta V = 2750$ m/sec.




## Campsite

- Booster enters elliptic orbit; expended.
- 2nd stage goes to LLO for checkout & alignment; after a few orbits, it proceeds to surface; not returned.
- Booster TLI total $\Delta V = 2450$ m/sec.
- 2nd stage total $\Delta V = 3822$ m/sec.

# Campsite

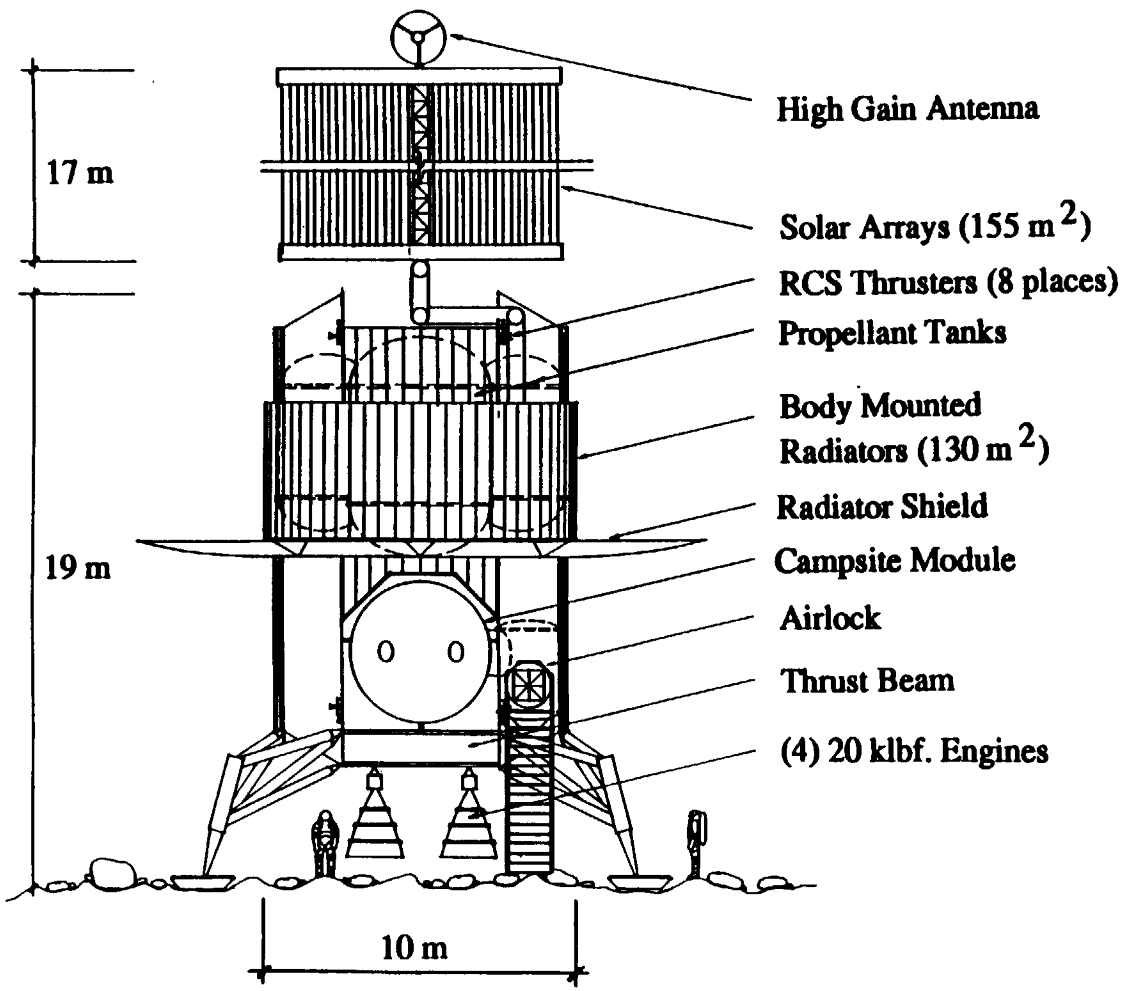
The Campsite is a complete small surface base that can support a crew of four for a period of 30 to 60 days. The campsite habitat is derived directly from the current Space Station Freedom reference 6-rack length module. The hab module is located below the propellant tanks for easy surface access, but above the engines to permit engine-out gimbaling. Radiators are body mounted with a "petal-type" deployable surface shield. Solar arrays are stowed above the propellant tanks and are deployed to track the sun with the high-gain antenna above. The structure of the vehicle stage consists of intersecting shear panels. Subsystems mounted in this structure are enclosed by a corrugated metal skin. This system allows "cut-outs" for airlock access and module window viewing.

The boost stage propellant tank volumes allow stage refurbishment if the necessary propellant (~20 mt) is included for an all-propulsive capture at Earth after the release of the lander in a TLI burn. This can be accomplished without impact to hardware design because of boost stage tank commonality with the CV lander which requires a 75 mt propellant load.

# Campsite



## Surface Configuration




## Mass Statement

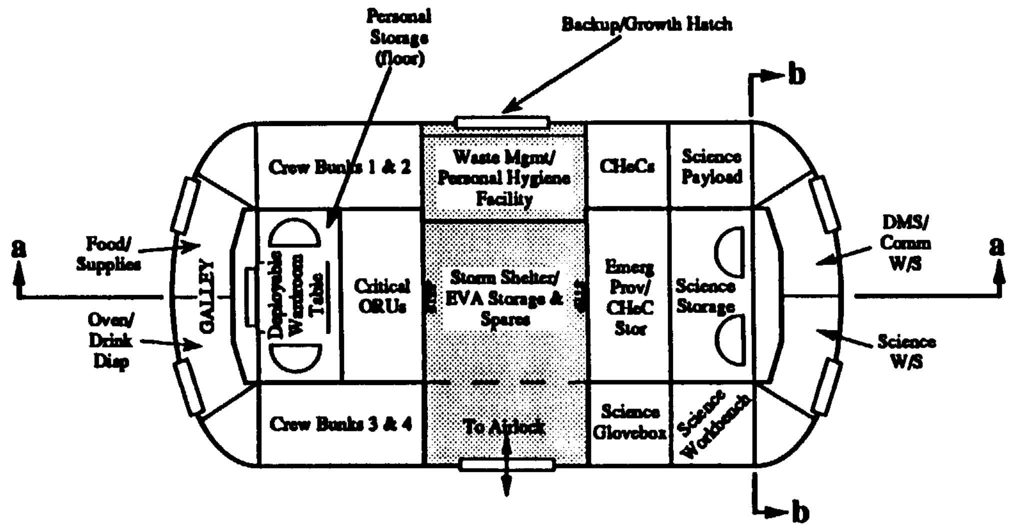
| | |
|---|---|
| **Boost LTV** | |
| Inerts | 10.6 |
| Propellant | 71.7 |
| | **82.3 mt** |
| **Lander** | |
| Inerts | 10.6 |
| Propellant | 57.1 |
| Campsite | 31.6 |
| | **99.3 mt** |

## Internal Configuration

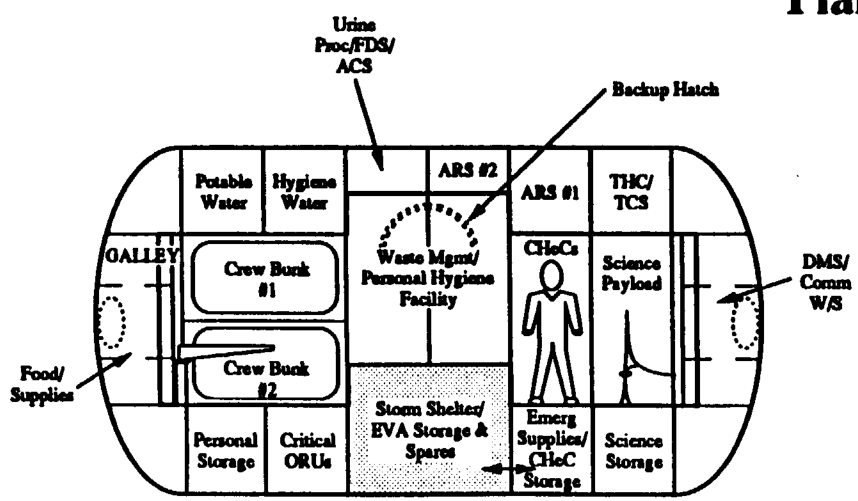
The Lunar gravity environment, although only one-sixth that of Earth, still dictates manned Campsite orientation and operations. Thus, equipment with which the crew mainly interacts (workstations, payloads, galley, etc.) is placed along the module's vertical walls. Horizontal bunks (which may be enclosed for noise reduction and privacy) are also necessary. Lunar dust promises to be a problem even inside the module; therefore, only storage racks are placed in the floor (where most dust will likely settle), ECLSS racks are in the ceiling, and most utilities are routed through the ceiling standoffs. Windows are needed for both EVA safety and psychological reasons. By placing two windows on each end dome, complete over-lapping fields of vision may be provided without interference with the LTV structure envelope or the launch payload shroud. A second hatch (located on the module wall opposite the Airlock) serves a dual role as backup (unpressurized) ingress/egress portal and as a growth hatch for possible later expansion. Access to this hatch requires removal or lowering of the PHF; later growth may need to include volume to make up for these "lost" rack spaces. As shown, an internal storm shelter is also provided which would accommodate 4 crew for 3 days and would provide protection necessary for a 1972-like solar flare.

# Internal Configuration

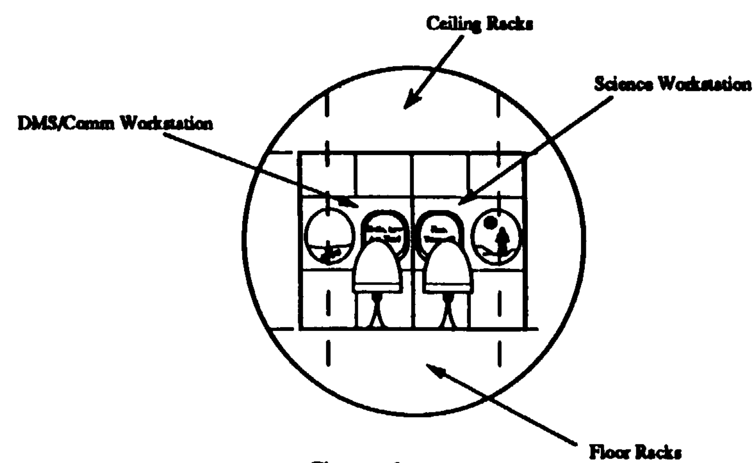





Plan View




Section a-a




Section b-b

# Subsystem Summary

This chart presents the mass, volume, and power summaries for each major system (both external and internal) which comprise the lunar Campsite. Many of the numbers given here have been taken directly or derived from Space Station Freedom reports. Not included on this chart are requirements for either the boost or lander stage. This Campsite concept incorporates both closed ECLS and closed power systems to allow multiple, non-contiguous missions. The closed power system is accomplished using regenerable fuel cells with high pressure gaseous reactants. ECLSS also includes make-up and emergency gases sized for one mission. Since the crew delivery vehicle serves as a quick escape from the Campsite, most of these systems only provide up to one failure tolerance. The storm shelter mass assumes some protection from the lunar surface and from the Campsite itself. Peak power expected during lunar day use is 17.8 kWe (excluding fuel cell reactant regeneration requirements).

# Subsystem Summary



| SYSTEM | MASS (kg) | VOLUME ($m^3$) | POWER (kWe) | | COMMENTS |
|---|---|---|---|---|---|
| | | | Cont | Non-C Avg | |
| Structures | 6500 | 122.6 Module*<br>7.0 Airlock | ---- | 0.3 | *Total volume which contains internal component volumes |
| Crew Systems | 3085 | 67.0 | 1.0 | 0.65 | |
| ECLSS | 3725 | 10.1 | 3.9 | 0.7 | Closed ECLSS (incl water charge; does not incl expendables) |
| Internal EPS | 495 | 0.75 | 0.4 | ---- | |
| Internal TCS | 405 | 1.5 | 0.03 | 0.5 | |
| DMS/Communications | 545 | 2.8 | 0.9 | 0.2 | Includes workstation |
| Internal Audio/Video | 50 | 0.75 | ---- | 0.3 | |
| C&T | 100 | External | 0.1 | ---- | |
| External TCS | 765 | External | (3.2)<br>[0.3] | ---- | 3.2 kWe during Lunar day only<br>0.3 kWe during Lunar night only |
| Power: H/W (incl arrays)<br>Reactants/Tanks | 1065<br>5600 | External<br>External | ----<br>---- | ----<br>---- | Regenerable Fuel Cell System |
| Science | 2485 | 10.0 | 0.75 | 0.72 | Includes one 520 kg rover |
| Storm Shelter | 3465 | 12.0 | ---- | ---- | |
| 15% Growth | 3350 | 12.4 | ---- | ---- | Excludes Science & Storm Shelter |
| TOTAL | 31635 | 117.3 | (10.28)<br>[7.38] | 3.37 | |

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# Structure System Assumptions

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- STCAEM Hab Trade structure system
- Subsystem structure mass includes components which vary with module length (e.g., ducting, plumbing, etc.)
- Airlock derived from SSF crewlock
- Barrel section length varies by rack equivalent widths (1.1m)
- Meteoroid/impingement shielding provided by surrounding LTV structure

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# Structure System Summary



| System | Mass (kg) | Source/Comments |
|---|---|---|
| 2 end domes | 325 | STCAEM Hab Trade/Aluminum (includes MLI) |
| 2 hatch assemblies | 844 | Space Station Freedom/Aluminum |
| 2 adapter bulkheads | 207 | Space Station Freedom/Aluminum |
| 2 reinforcing rings | 300 | Space Station Freedom/Aluminum |
| External stairs | 100 | Boeing Study/Aluminum |
| Airlock | 1,290 | Space Station Freedom/Aluminum |
| Monocoque barrel | 104 kg/m | STCAEM Hab Trade/Aluminum (includes MLI) |
| Internal Structure | 225 kg/m | STCAEM Hab Trade/Aluminum (10% A&I, 5% Secondary) |
| Mechanisms | 40 | SSF SE21 (7/15/90) - Mass Properties |
| • ECLSS plumbing | 24 kg/m | SSF SE21 (7/15/90) - Mass Properties |
| • DMS lines | 30 kg/m | SSF SE21 (7/15/90) - Mass Properties |
| • EPS lines | 51 kg/m | SSF SE21 (7/15/90) - Mass Properties |
| • IAV lines | 3 kg/m | SSF SE21 (7/15/90) - Mass Properties |
| • TCS lines | 77 kg/m | SSF SE21 (7/15/90) - Mass Properties |

Structure Formula Based on Volume:
$\Sigma M = 3{,}106 + [514 \times (\text{barrel length in meters})]$

Volume Data:
$\Sigma$ Endcone $V = 22.3\ m^3$
$\Sigma$ Barrel $V/m = 15.2\ m^3/m$

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# Crew Systems Assumptions



- Horizontal privacy bunks provided:
  - Extended duration (up to 60 days) Lunar stay
  - Internal noise unknown
- Crew Health Care equivalent to SSF PMC
  - SSF EMCC CHeCs may be optimum
- Two windows provided in each end dome:
  - Internal end dome racks chosen to allow viewing
  - Dual windows allow full view without LTV or launch shroud interference
- Absolute minimum free volume requirements observed for 1-2 month stay (20% uncertainty factor included)

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# Crew Systems Summary



| Crew Systems | Mass (kg) | Volume ($m^3$) | Power (kWe) | | Source/Comments |
|---|---|---|---|---|---|
| | | | Cont | Non-C Avg. | |
| Bunks | 400 | 8.00 | -- | 0.05 | Estimated |
| Personal Storage | 100 | 2.00 | -- | -- | Space Station Freedom |
| Crew Health Care | 825 | 3.00 | 0.17 | 0.05 | SSF PMC |
| Table and Chairs | 35 | 1.00* | -- | -- | Boeing study (12/12/88) |
| Personal Hygiene/Waste Management | 225 | 4.00 | -- | 0.03 | Space Station Freedom |
| Galley/Storage | 360 | 4.00 | -- | 0.25 | SSF Galley Racks (1/2 of SSF Power Duty Cycle Assumed) |
| EVA Suite Maintenance | 500 | 6.90 | 0.7 | 0.20 | Space Station Freedom |
| External EVA Equipment | 115 | -- | -- | -- | Space Station Freedom |
| Lights | 50 | -- | 0.1 | 0.05 | STCAEM Lunar Module Study |
| Tools | 25 | Gen. Sto. | -- | -- | STCAEM Lunar Module Study |
| Critical ORUs/Gen. Sto. | 350 | 2.00 | -- | -- | Space Station Freedom |
| Emergency Provisions | 100 | 0.50 | -- | 0.02 | Space Station Freedom |
| Free Volume | -- | 35.33** | -- | -- | Living Aloft by Mary Connors (NASA/Ames) |
| TOTAL | 3,085 | 66.73 | 0.97 | 0.65 | |

*Stowed volume only

**Includes 20% uncertainty factor



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# ECLSS Assumptions



- Closed loop (comparable to SSF EMCC)
- Consumables (food, resupply, spares) delivered with crew
- No dedicated Avionics Air System
- No refrigerators or freezers (drinking water cooling provided)
- Portable fire extinguishers
- Dual string cabin air cooling system
- Dual string carbon dioxide removal/reduction assemblies
- Dual string oxygen generator assembly
- Single string Atmosphere Composition Monitoring Assembly
- Single string Trace Contaminant Control system
- Water Recovery and Management includes both potable and hygiene water
- Atmosphere Control System includes make-up (leakage plus 10% airlock loss per EVA) and emergency gases (and tankage) sized for one mission
- Scheduled use of hygiene water may permit occasional showers
- Internal pressure = 14.7 psia

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# ECLSS Summary



| ECLSS Subsystems | Mass (kg) | Volume ($m^3$) | Power (kWe) | | Source/Comments |
|---|---|---|---|---|---|
| | | | Cont | Non-C Avg. | |
| THC (Structures) | 370 (17.4) | 2.0 | 0.84 | -- | POWER: SSF/SE19 Electrical Power and Energy Reports (D683-10238-20) |
| FDS (Structures) | 24 (21) | 0.05 | -- | -- | VOLUME: SSF Rack Alloc. |
| ACS (Structures) | 562 (12) | 0.05 + External Tanks | 0.01 | 0.05 | MASS: SSF/SE21 Mass Properties Report D683-10275-6 |
| ARS (Structures) | 1383 (1.1) | 3.0 | 2.78 | 0.16 | |
| WRM (Structures) | 1385 (18) | 5.0 | 0.27 | 0.49 | |
| TOTAL | 3724 (23.6) | 10.1 | 3.90 | 0.70 | |

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# Internal Systems Assumptions



- Includes Electrical Power System (EPS), Thermal Control System (TCS), Data Management System (DMS), and Internal Audio/Video (IAV) components located in enddomes/hatchways (standoff components included with Structures mass):
  - Each system based on SSF endcones (EPS and TCS scaled for Campsite)
  - SPDA/TPDA modules (2 per powered "rack-based" function) charged to appropriate "rack-based" function
  - DMS/Comm mass includes a workstation (based on SSF ECWS)

- Internal TCS pump package, heat exchanger, and plumbing serve both systems and payloads

- Each "rack-based" function (ECLSS, DMS/Comm Workstation, Payloads, etc.) includes necessary internal rack system components, except:
  - No avionics air
  - Rack structure accounted for in Structures mass
  - ECLSS (including FDS) accounted for in ECLSS mass

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# Internal Systems Summary



| Internal Systems (except ECLSS) | Mass (kg) | Volume ** ($m^3$) | Power (kWe) | | Source*/Comments |
|---|---|---|---|---|---|
| | | | Cont | Non-C Avg. | |
| EPS | | | | | |
| Exo-rack (minus standoff) | 495.0 | 0.75 | 0.4 | ----- | 1/2 of SSF SPDA & DDCU Numbers |
| TCS | | | | | |
| Exo-rack (minus standoff) | 328.4 | 0.75 | ----- | ----- | 1/2 of SSF Central Thermal Bus Numbers |
| Pump package/HX | 76.1 | 0.7 | 0.03 | 0.52 | |
| Int. TCS Subtotal | 404.5 | 1.45 | 0.03 | 0.52 | |
| DMS | | | | | |
| Exo-rack (minus standoff) | 173.6 | 0.75 | 0.36 | ----- | |
| DMS/Comm W/S | 372.4 | 2.0 | 0.55 | 0.22 | Based on SSF ECWS |
| DMS Subtotal | 546.0 | 2.75 | 0.91 | 0.22 | |
| IAV | | | | | |
| Exo-rack (minus standoff) | 46.6 | 0.75 | ----- | 0.26 | |

*SSF WP01 SE19 (4/15/90)
SSF WP01 SE21 (7/15/90)
Level II Power Allocation Report and Margin Analysis, Rev. A SHQ-321-0008A, Nov. 1, 1990

**Total Exo-rack (minus standoff) volume assumed ~ 3.0 $m^3$ (0.75 $m^3$ for each system)

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# External Systems Assumptions



- Includes Thermal Control (TCS) and Communications & Tracking (C&T) systems

- External TCS

  - Body Mounted Radiator (BMR) chosen
  - Baseline includes single loop heat pump for external TCS
  - Radiator sized to account for worst sun angle case
  - Daylight Power = 17.8 kW
  - TCS heat pump requires 3.2 kW during the lunar day only
  - Shield mass accounts for deployable system

- External C&T system

  - Based on Lunar Rover work
  - High gain antenna assumed deployable with solar array

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# External Systems Summary



| External Subsystems (except Power) | Mass (kg) | Volume ($m^3$) | Power (kWe) | | Source/Comments |
|---|---|---|---|---|---|
| | | | Cont | Non-C Avg. | |
| C&T | | | | | |
| Antennas, lines, etc. | 20 | | 0.10 | ---- | |
| Deployable structure | 80 | | -- | ---- | |
| C&T Subtotal | 100 | | 0.10 | ---- | From Lunar Rover estimates |
| TCS | | | | | |
| Transport loop | 300 | | (3.2) | ---- | Daylight power req'ts only |
| | | | [0.3] | ---- | Nighttime power req'ts only |
| Radiator | 349 | | ---- | ---- | |
| Shield | 118 | | ---- | ---- | |
| Ext. TCS Subtotal | 767 | | (3.2) | ---- | Lunar day TCS uses heat pump |
| | | | [0.3] | ---- | |

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# Power System Assumptions



- Lunar day length = 335 hours; Lunar night length = 375 hours
- Regenerative fuel cells reactants stored at high pressure (3000 psia)
- Solar arrays provide Lunar day peak power needs
- Fuel cells provide Lunar night average power needs
- Peak power loading is the sum of continuous power plus the power required for other components that may be activated at the same time (17.8 kW during Lunar day and 14.6 kW during Lunar night)
- Average power is the sum of continuous power plus the product of non-continuous power and duty cycle (13.6 kW during Lunar day and 10.75 kW during Lunar night)
- Electrolyzer for fuel cell reactants requires another 17.0 kW power during Lunar day (solar array sized for 34.8 kW total power)

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# Power System Summary



| Power System Components | Mass (kg) | Size |
|---|---|---|
| Solar Arrays | 250.1 | 153.3 $m^2$ |
| Habitat Power Mgmt & Dist | 271.5 | |
| Fuel Cell System | | |
| - Hardware | 470.4 | 0.53 $m^3$ |
| - Reactants and Tankage* | 5673.5 | 21.8 $m^3$ |
| TOTAL | 6665.5 | |

* Includes 2 $O_2$ tanks (at 3000 psi, 300 K), 3 $H_2$ tanks (at 3000 psi, 300 K), and 1 $H_2O$ tank

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# Science Assumptions



- A representative set of internal science equipment selected:
  - Provides Campsite with basic lab needs
  - Generic science payload may accommodate life science experiment
  - Locating science glovebox adjacent to workbench may allow combination into Maintenance Workstation (MWS)

- Science workstation
  - External science monitoring
  - Data reduction
  - Telerobot management

- Science glovebox
  - Isolated experiments
  - Sample evaluation

- Science workbench
  - Open work area
  - Diagnostics/power tools

- Science storage
  - Payload changeouts possible
  - Supplies

- External science equipment carried by Campsite consists of one 520 kg Rover (remainder of external science brought by crew)

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# Science Summary



| Science | Mass (kg) | Volume ($m^3$) | Power (kWe) | | Source*/Comments |
|---|---|---|---|---|---|
| | | | Cont | Non-C Avg. | |
| Workstation | 372.4 | 2.0 | 0.55 | 0.22 | Based on SSF ECWS |
| Glovebox | 410.0 | 2.0 | 0.03 | 0.07 | Based on SSF Materials Proc Glovebox (1/2 of NC power) |
| Workbench | 381.1 | 2.0 | 0.03 | 0.195 | Based on SSF Life Sciences Workbench (1/2 of NC Power) |
| Payload | 400.2 | 2.0 | 0.07 | 0.23 | Based on generic 3 kW SSF payload rack |
| Storage | 400.2 | 2.0 | 0.07 | ----- | Based on payload rack |
| Unpressurized Rover | 520.0 | External | ----- | ----- | Based on current Boeing rover study |
| Science Subtotal | 2483.9 | 10.0 | 0.75 | 0.715 | |

*SSF WP01 SE19 (4/15/90)
SSF WP01 SE21 (7/15/90)
Level II Power Allocation Report and Margin Analysis, Rev. A SHQ-321-0008A, Nov. 1, 1990

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# Storm Shelter Assumptions



- Assumed acceptable dosage of 25 rem
- Storm shelter supplies included as part of emergency provisions (see Crew Systems)
- Power, C&T, DMS, etc. are accessed within storm shelter via normally functioning equipment
- Campsite components (structure, systems, etc.) assumed to provide one-fourth of required shielding
- Storm shelter located under floor near middle of module:
  - Protection required based on 1972 solar flare event
  - Lunar surface effectively reduces radiation flux by 50%
  - Water couches provide 30° of protection along each module wall
  - Lower 120° protected by lunar surface
  - Additional protection added above and along internal sides of shelter
- ECLSS use of storm shelter water in exchange for brine, contaminated water, etc. may be feasible for reducing initial charging, consumable resupply, etc.
- Detailed analysis required to verify and refine shelter estimates

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# Storm Shelter Summary



| Storm Shelter | Mass (kg) | Volume ($m^3$) | Power (kWe) | | Source/Comments |
|---|---|---|---|---|---|
| | | | Cont | Non-C Avg. | |
| Water Couches | 734 | | ---- | ---- | Provides 30° of coverage along each module wall * |
| Structure | 500 | | ---- | ---- | Assumed equivalent to 5+ SSF racks |
| Additional Shielding | 2230 | | ---- | ---- | Supplements top and internal sides protection |
| Shelter Subtotal | 3464 | 12.0 | ---- | ---- | Highly sensitive to vehicle configuration |

* Lower 120° assumed to be protected by lunar surface

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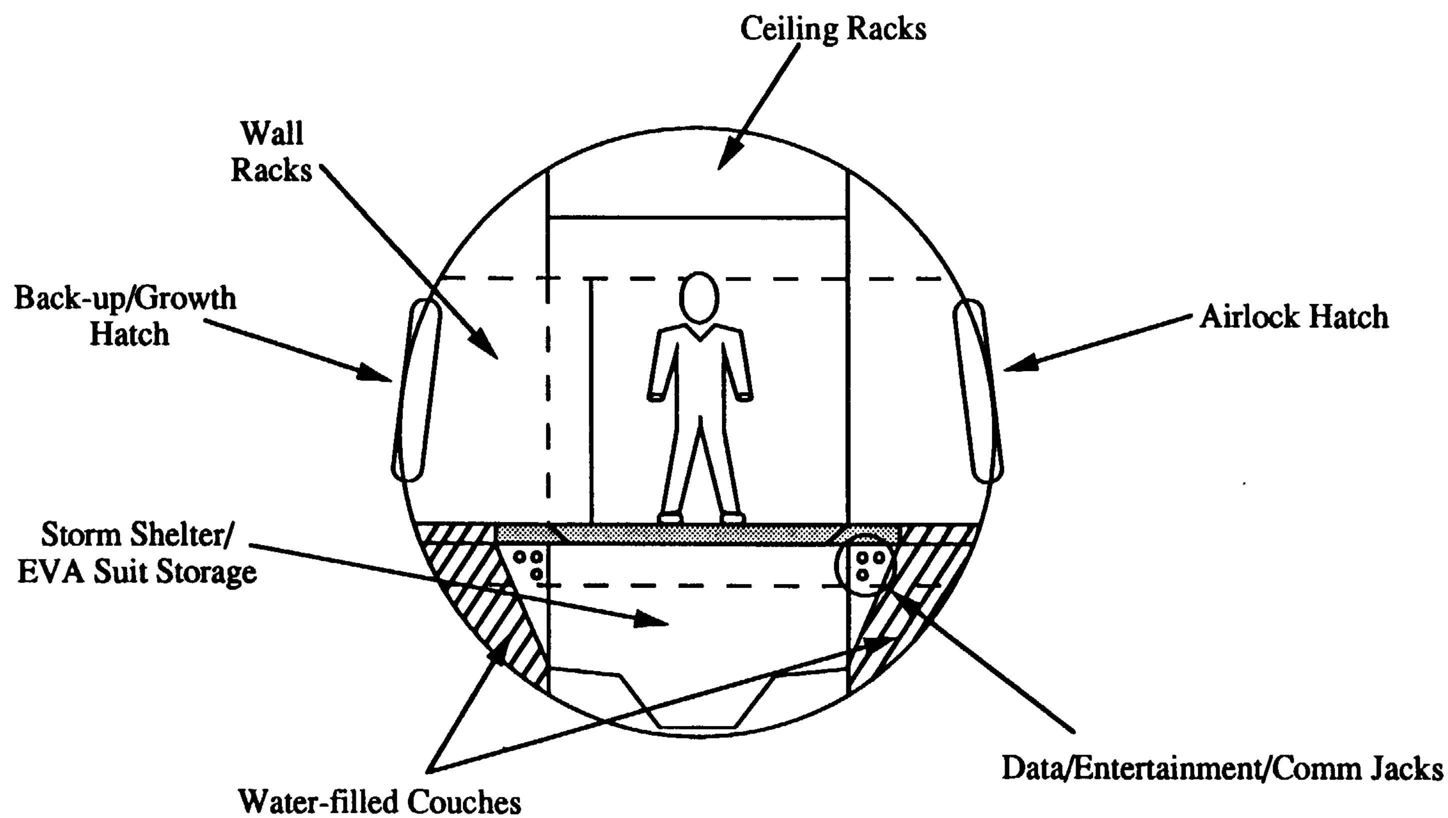
# Storm Shelter




(Emergency Supplies include food, drink, books, P-MPAC for statusing/monitoring, communication headsets, medical/dental supplies, minor surgical instruments, flashlights,etc.)

## Cross Section



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# Open Systems Option Summary

An option to the baseline closed ECLS and fuel cell power systems concept was explored in which these two systems were "opened up" to reduce mass. As shown on this chart, this option is identical to the baseline except for ECLS and power systems. The open power system uses cryogenic fuel cell reactants (which are brought by each crew, including the first) for lunar night power. A regenerable fuel cell (RFC) system is included to provide 1 kW "keep alive" power for each of the lunar nights during unoccupied periods.

Other options which were considered but are not shown here include deferring the closed ECLSS functions of $CO_2$ reduction and $O_2$ generation to the daylight periods only (thus saving fuel cell reactant mass). Deferral of the two ECLSS functions was examined for its impact to both the ECLS and power systems. Although this approach does reduce night time power requirements, additional ECLSS units for daytime operation as well as storage gases and tanks are needed. The preliminary benefit was found to only be on the order of 200 - 300 kg; thus, due to the added complexity involved, this was not deemed a viable option. These options are discussed here only to identify possible variations to the concept; however, the baseline version is regarded as being best able to meet a variety of mission needs.

# Open Systems Option Summary



| SYSTEM | MASS (kg) | VOLUME ($m^3$) | POWER (kWe) Cont | POWER (kWe) Non-C Avg | COMMENTS |
|---|---|---|---|---|---|
| Structures | 6500 | 122.6 Module*<br>7.0 Airlock | ---- | 0.3 | *Total volume which contains internal component volumes |
| Crew Systems | 3085 | 67.0 | 1.0 | 0.65 | |
| ECLSS | 1070 | 5.1 | 2.2 | 0.2 | Open ECLSS (does not include expendables or consumables) |
| Internal EPS | 495 | 0.75 | 0.4 | ---- | |
| Internal TCS | 405 | 1.5 | 0.03 | 0.5 | |
| DMS/Communications | 545 | 2.8 | 0.9 | 0.2 | Includes workstation |
| Internal Audio/Video | 50 | 0.75 | ---- | 0.3 | |
| C&T | 100 | External | 0.1 | ---- | |
| External TCS | 635 | External | (2.7)<br>[0.3] | ---- | 2.7 kWe during Lunar day only<br>0.3 kWe during Lunar night only |
| Power: H/W (incl arrays)<br>RFC "keep alive" | 550<br>660 | External<br>External | ----<br>---- | ----<br>---- | Does not incl 1490 kg of reactants & tankage brought by Crew |
| Science | 2485 | 10.0 | 0.75 | 0.72 | Includes one 520 kg rover |
| Storm Shelter | 3465 | 12.0 | ---- | ---- | |
| 15% Growth | 2115 | 11.7 | ---- | ---- | Excludes Science & Storm Shelter |
| TOTAL | 22160 | 111.6 | (8.08)<br>[5.68] | 2.87 | |





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# Possible Campsite Missions

Outlined on this chart are candidate uses for both versions of the Campsite concept. The closed systems version refers to the baseline concept discussed throughout this package, which incorporates both closed ECLS and regenerable fuel cell power systems. The open systems version is an option to the baseline Campsite which includes an open ECLSS and an open fuel cell power system. The baseline Campsite concept is recommended for a broader range of possible missions.

The open loop systems version of the Campsite is lighter than the baseline; however, open loop systems will increase resupply requirements and subsequently complicate operations. Resupply for the open loop systems version include fuel cell reactants, atmospheric oxygen, and water. These consumables must be carried by the CV (in addition to the standard food, crew, and science equipment), transported to the Campsite, installed, and checked out with a considerable expenditure of crew effort. Based on 42 day stays, preliminary results show that resupply mass required for the open systems option appears to crossover with the closed systems concept at the fourth visit. For 60 day stays, this crossover will occur on the second visit. Thus, due to the resupply needed, only those missions which require shorter stays or limited revisits appear feasible for the open systems version.

ADVANCED CIVIL SPACE SYSTEMS

# Possible Campsite Missions

BOEING

- Early overnight surface visit/operations
- Remote site exploration base
- Man-tended science station
- Permanent base emplacement:
  - Construction shack
  - Initial infrastructure
  - Emergency shelter

**Candidate uses for open systems version of Lunar Campsite**

**Candidate uses for closed systems version of Lunar Campsite**

# Lunar CRV

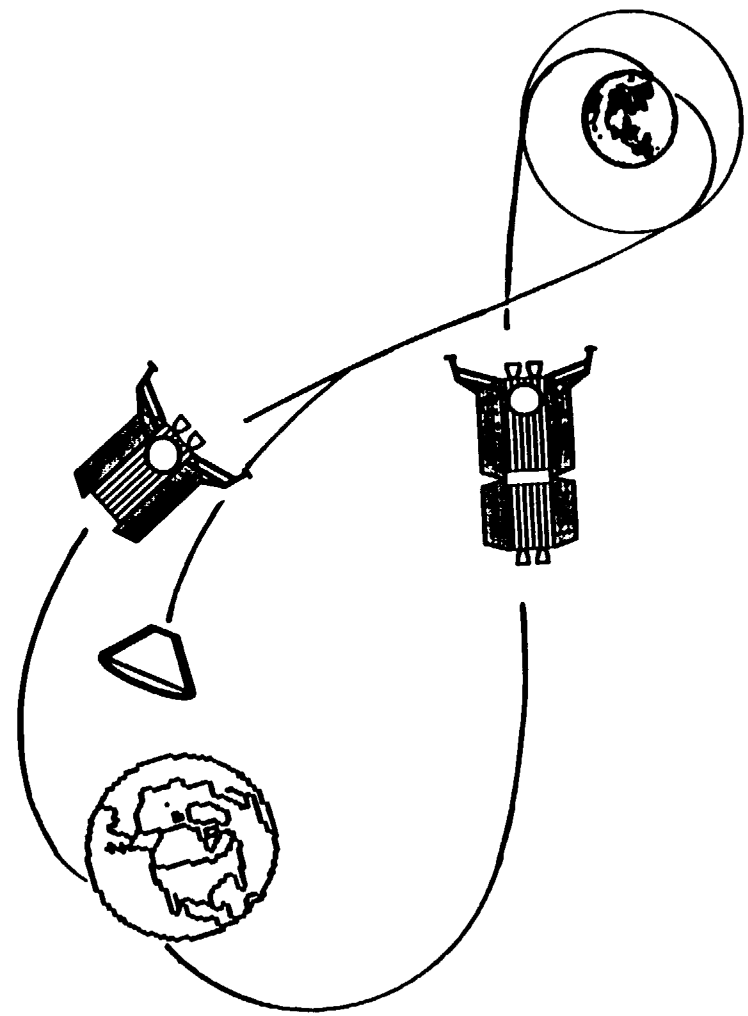
- Mission description and design assumptions for the Lunar CRV are listed below

# Lunar CRV



## Mission Modes

- 10 day nominal duration for 4 crew while attached to transfer vehicle (round trip)
- 48 days on Lunar surface in "powered down" mode without crew (42 days plus contingency)
- Separation from LTV 12 hours or less prior to direct Earth entry
- Parachute "wet" landing



## Assumptions

- Direct entry CRV need not be common with SSF ACRV due to higher entry velocity
- CRV payload mass is relatively low( crew, surface samples), allowing parachute landing
- CRV propulsion limited to ACS
- LTV / service module provides power and life support consumables prior to earth return

# Crew Vehicle (CV)

The Crew Vehicle (CV) is very similar to the Campsite. The CV does not, however, have radiators or solar arrays. The vehicle stacks are essentially common in that they utilize the same structure system and engines, the same propellant tank volume, the same cargo bay in which the CRV and payloads are incorporated, and the same RCS locations. The payload delivered with the CRV (crew supplies, rover and science), which are not shown on the chart, are integrated in the rear portion (with respect to the CRV) of the CV cargo bay.

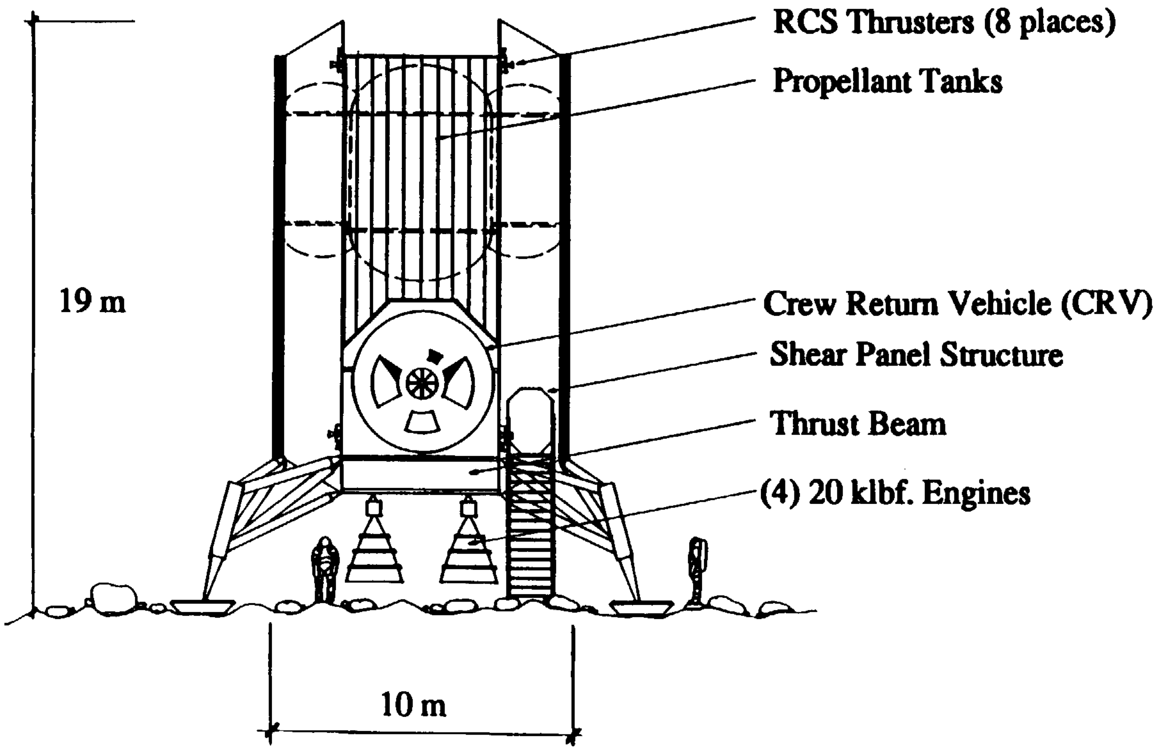
The concept provides flexibility in responding to various ETO alternatives or lander mass growth by shifting $\Delta V$ requirements between the boost and lander stages, especially if the boost stage were considered expendable.

The CV boost stage is identical to the Campsite boost stage and is also capable of reuse with an all-propulsive capture at LEO. If reutilization is not desired, which is the reference case, the boost stage incorporates a smaller propellant load and is expended, thus reducing ETO requirements. If detailed analysis indicates inadequate savings from tank commonality and reutilization is not desired, the boost stage mass could be reduced by incorporating smaller propellant tanks.

# Crew Vehicle (CV)



## Surface Configuration




## Mass Statement

| | |
|---|---|
| **Boost LTV** | |
| Inerts | 10.6 |
| Propellant | 72.0 |
| | **82.6 mt** |
| **Lander** | |
| Inerts | 10.6 |
| Propellant | 74.4 |
| CRV | 8.2 |
| Crew & Supplies | 3.9 |
| Rover and Science | 2.7 |
| | **99.8 mt** |

# Delivered With Crew Vehicle

Given on this chart are the equipment and resources to be brought by the crew in order to accommodate their stay at the Campsite. It is expected that all personal gear and EVA equipment would be delivered by each crew for their visit; of course, the crew vehicle will contain the necessities for both the out-bound and in-bound transits. Resupply of the Campsite is given for both the baseline closed systems version and the open systems option. Life support resources include leakage/repress/EVA gases and tankage (which are included in the closed systems baseline for the first mission) as well as food (the open systems option also requires potable and hygiene water as well as oxygen resupply); expendables include filters and other such changeout parts. The open systems option also requires its cryogenic fuel cell reactants to be resupplied for each overnight stay. An unpressurized, robotic/manned rover is brought down by the Campsite; an additional rover is brought by the first Campsite crew to accommodate redundancy and rescue. Subsequent crews would be required to bring rovers as the rover lifetime dictates. Science equipment would be determined by the needs of specific science missions.

# Delivered With Crew Vehicle



- Crew related equipment:
  - Gear (clothing, etc.)
  - EMUs (6 for 4 crew)
  - In-Transit Life Support

- Campsite resupply (based on 42 day stays):

| Description | Closed Systems | Open Systems Option |
|---|---|---|
| Life Support Resources | Consumables* 838<br>Expendables 302 | 1912 **<br>84 |
| Power System Reactants | Regenerative System | 1490 kg (incl tanks) |
| Unpressurized Rover | 520 kg (one rover)*** | 520 kg (one rover)*** |
| Science Equipment | TBD | TBD |

* The closed systems Campsite includes 501.5 kg for leakage/repress/EVA gases and tankage necessary for first mission (above resupply number is total for subsequent missions); every resupply would include food

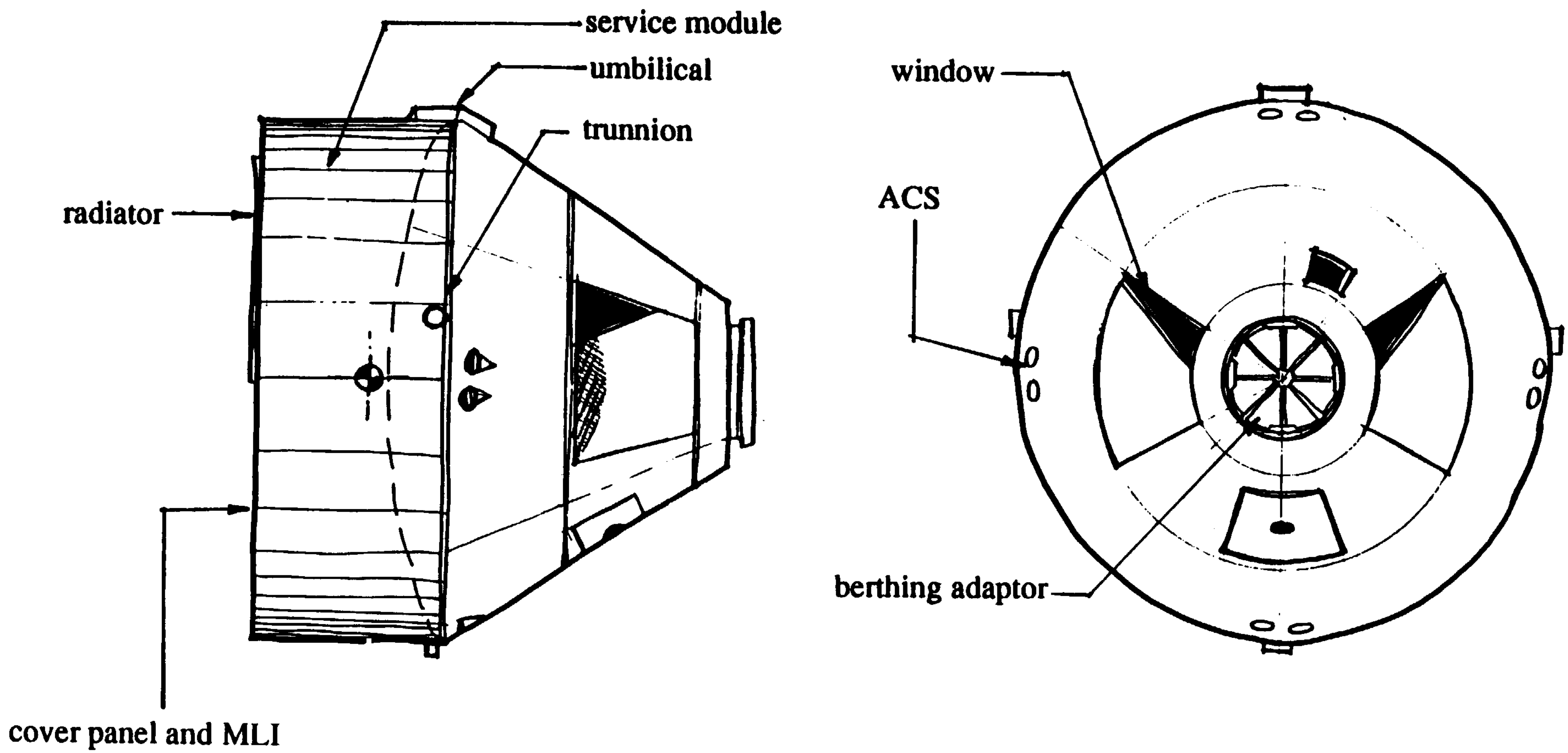
** Open cycle fuel cell water production and exchange with storm shelter water may be used to reduce/eliminate water resupply after the first resupply mission (these numbers do not reflect this option)

*** First crew mission brings another rover to provide redundancy and rescue to Campsite rover (additional rovers may need to be brought depending on rover lifetime)

# Lunar CRV Option

The side and front views shown below illustrate the crew return vehicle as modified to perform a Lunar excursion mission. Configuration issues included crew visibility for landing, surface access, and consumables storage for the required 60 day mission duration. The conical capsule shape has been modified by providing cutout sections in the forward part of the structure to allow the crew to see landing structure and footpads during descent and touchdown. The service module shown covering the ablative re-entry heat shield houses primary power and life support consumables, and power generating equipment for the crew module and transfer vehicle. The service module is shed after the CRV separates from the CV lander stage a couple of hours prior to entry. Surface access is achieved through the hatch at the bottom of the capsule.

# Lunar CRV Option

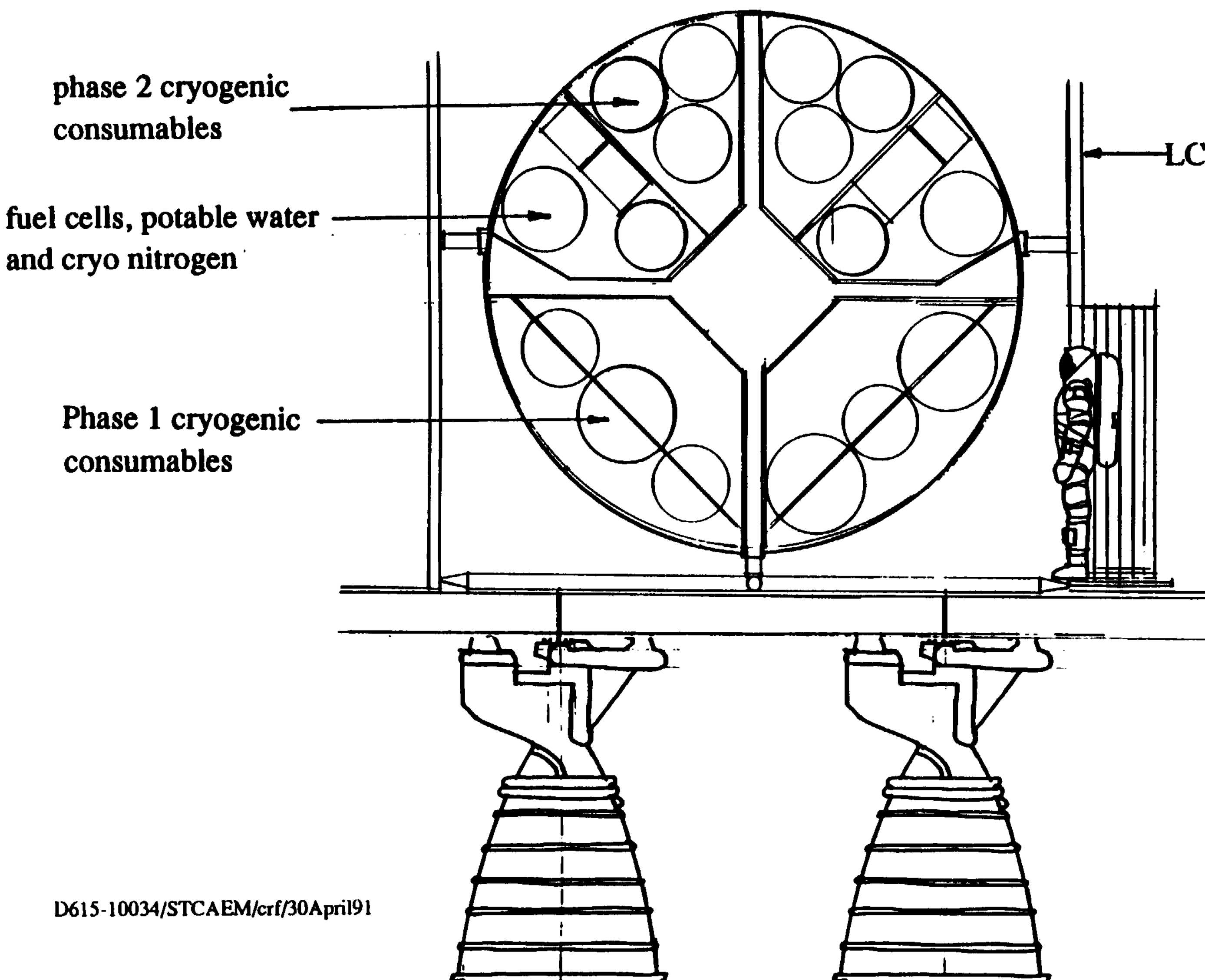


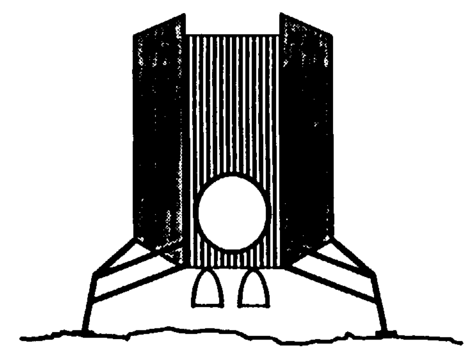
# Section Through Service Module

A view of the service module with radiator, cover plate and MLI removed is provided. Shown are locations for cryogenic H2, O2 and Nitrogen tanks that supply both the life support and power generating equipment. Consumables have been divided into two sections, phase 1 indicating the LEO to Lunar surface, plus 48 day surface stay portion of the mission. Phase 2 tanks provide supply for the CRV until the service module separates just prior to earth reentry. Phase 1 tanks are located in the lower quadrants of the service module structure for crew access while on the Lunar surface.

# Section Through Service Module





LCV on surface

# Preliminary CRV Mass Statement
# 4 Crew Lunar Option

Shown on the facing page is a breakdown of estimated weights for the lunar CRV.

# Preliminary CRV Mass Statement
## 4 Crew Lunar Option



| System | Mass kg |
|---|---|
| Structure | •1550 |
| Ablator and insulation | *400 |
| Landing Systems | *428 |
| GN&C | •503 |
| Power, Dist. and Control | 200 |
| Stabilization and Control | *250 |
| ECLS, Thermal Control | *450 |
| Crew Systems | *60 |
| 4 crew and EVA suits | 750 |
| **CRV Service Module** | |
| Structure | 1050 |
| Fuel Cells | 184 |
| Reactants and Tanks (cryo) | 1144 |
| Life Support O2/N2 (cryo) | 374 |
| Potable Water | 141 |
| 15% Growth | 752 kg |
| **Total Mass** | **8236 kg** |

* scaled from Apollo CM
• scaled from Boeing PLS

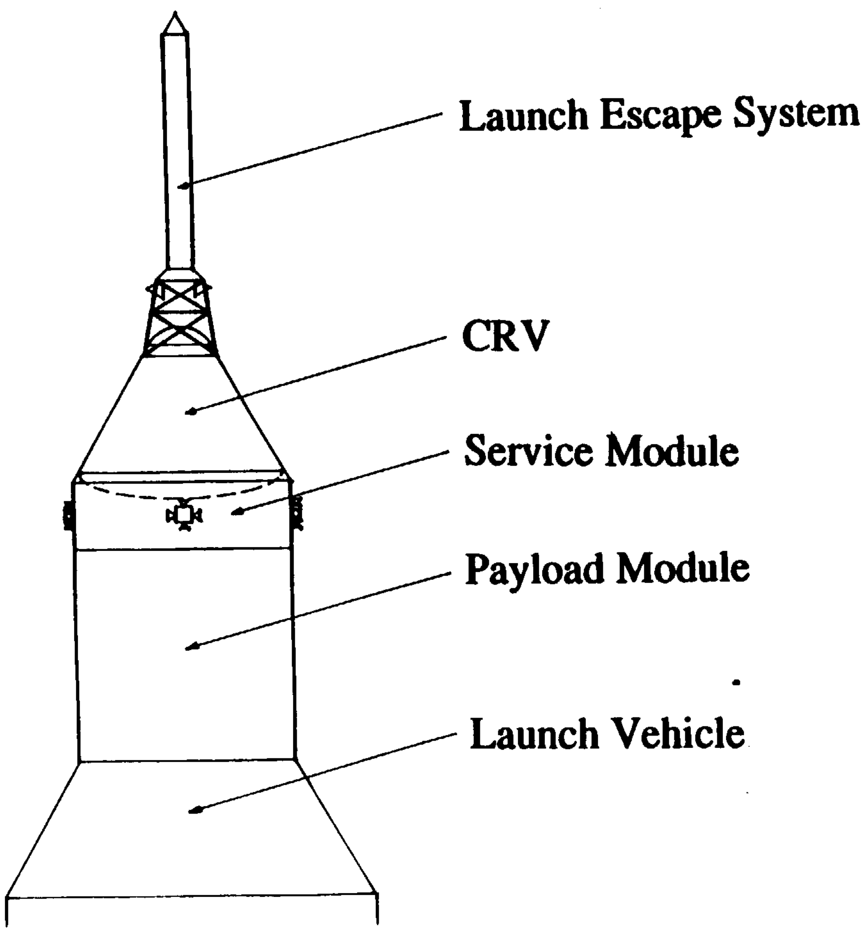
# CRV Launch Options

The Crew Return Vehicle (CRV) can be launched in any of three different ways: 1) integrally with the CV with the crew delivered separately, 2) on a man-rated expendable launch vehicle with the crew, to dock with the CV, or 3) in the Space Shuttle where the crew would transfer to the CRV in the Shuttle payload bay, separate, and dock with the CV.

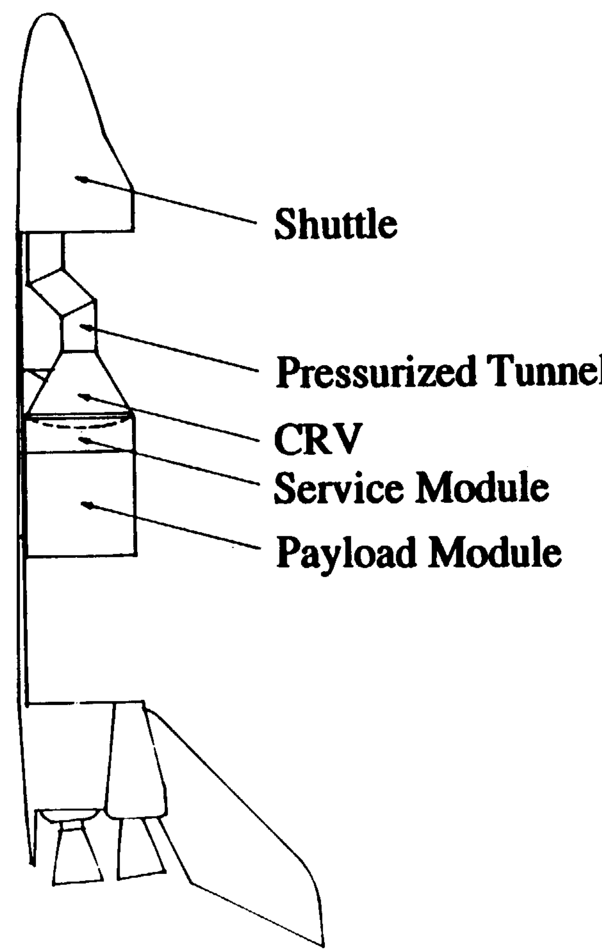
# CRV Launch Options



## Man-Rated Expendable Launch Vehicle




## Space Shuttle



# Complications Avoided

The Campsite concept was conceived to simplify lunar surface operations and to provide early exploration capabilities. The following chart lists nine major complications which are standard in traditional mission scenarios, and are avoided in the Campsite concept. The requirement of a surface infrastructure is avoided while still providing manned surface operations. One main vehicle type has been developed that can satisfy both boost and landing procedures, thus eliminating the need for a separate lander and transfer vehicle. Aerocapture has been avoided early in the program, however is not precluded later in the program, if desired. LEO assembly and infrastructure has been avoided by integrating the pieces on the ground and simply docking in LEO prior to TLI, much like was done in Apollo. Since simple docking in LEO is being used, there is no need for in-space propellant transfer because the boost stage and the lander stage are separate stages requiring only a structural interface. Since a direct-entry CRV is being used, the SSF rendezvous problems associated with nodal regression are eliminated. Since there are no LOR operations in LLO, the risk of failed rendezvous as well as abort wait times in LLO are eliminated. Since the crew has a separate surface hab to operate from while on the lunar surface (the Campsite), no separate transfer hab is required. All of these avoided complications make the lunar Campsite system a very attractive option to achieve an early, inexpensive and very visible SEI program milestone.

# Complications Avoided



- Surface infrastructure as a pre-condition for surface operations
- More than one vehicle type
- Aerocapture
- LEO assembly and infrastructure
- In-space propellant transfer
- SSF rendezvous on return
- Risk of failed rendezvous in LLO
- Abort wait times
- Separate transfer crew hab

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# Preliminary Conclusions



- Tandem Direct Lunar Campsite Concept meets desired goals, including:
  - Provision of significant early manned lunar science and exploration capability
  - Avoidance or reduction of some major operational and infrastructure concerns/requirements
  - Incorporation of common vehicle designs and existing/ near-term technology
  - Compatibility with 100 mt payload capable launch vehicle
- Closed systems Campsite masses 31.6 mt and allows multiple, non-contiguous stays of up to 60 days for 4 crew
- Open systems versions may be competitive for missions with shorter stays, limited revisits, and/or smaller launch vehicles
- Automated/robotic science and exploration may be possible from the Campsite during unoccupied periods

# Further Study

Radiation analysis of the reference Campsite concept needs to be performed to optimize configuration and mass analysis. Science requirements need to be defined better in order to enter the "point design phase" that is necessary to define the system. The biggest science issue is: "What can 4 crew do for 30 to 60 days with a reasonable amount of science mass?" Self-deploying and self-activating systems as well as robotic operations will play a large role in the success of the Campsite operations, and will require much further work in the future. ECLS and power are systems requiring more in-depth trade studies to be performed in the next couple of years. The question of resupply for non-contiguous occupation applies mainly to consumables as well as the crew and their supplies, but also to maintenance, repair, changeout and growth. Emergency and redundancy scenarios must be addressed so that requirements can be established which will feed system and subsystem design.

# Further Study



- Radiation analysis and protection for all mission phases
- Crew Vehicle (CV) airlock
- Campsite airlock definition/EVA suit storage and maintenance
- Science mission objectives/requirements:
  - rover use/lifetime
  - internal science complement
  - external science complement
- Robotics requirements/accommodations
- Degree of closure for ECLSS and power subsystems
- Power usage/budgeting
- Resupply and dormancy operations
- Self-deploying and self-activating systems design
- Redundancy and contingency scenarios
- Crew health care and maintenance requirements